Advanced Automotive Battery Initiative

A Government, Industry and Academia vetted White Paper led by the U.S. Army's and the Research, Development & Engineering Command's Tank-Automotive Research, Development & Engineering Center, (TARDEC)

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Advanced Automotive Battery Initiative

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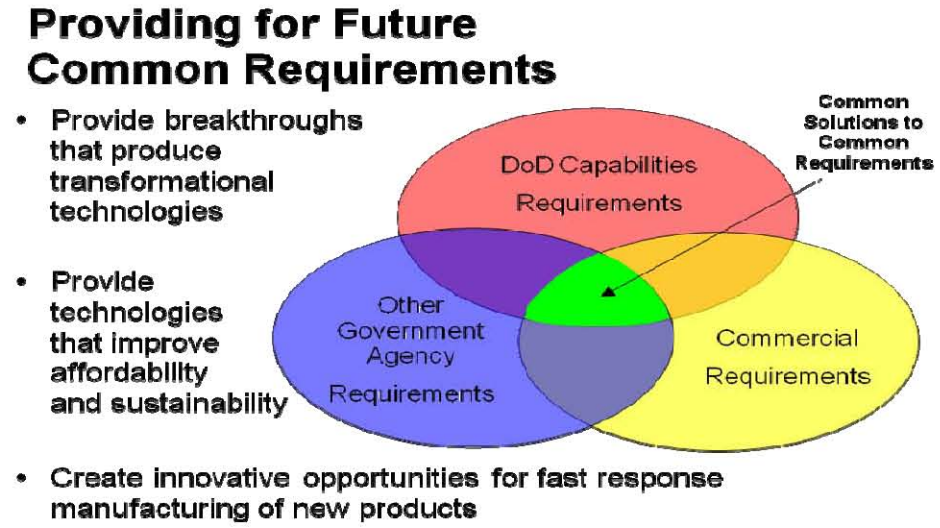
I. Objective

This initiative will provide the military with the highest quality domestically produced components at the lowest possible price. It will also provide domestic vehicle makers with a viable, cost effective domestic supply base for advanced automotive batteries. Support of an American base will also ensure that the military and domestic vehicle makers have access to future technological improvements of battery technology.

This objective will be met by establishing a detailed plan to develop the necessary supplier base and manufacturing technology to enable the domestic production of the advanced automotive battery cell, modules, and packs. Furthermore, this domestic base will be capable of satisfying both Department of Defense (DoD) and commercial vehicle applications. Passenger car, commercial truck, and transit battery volumes and applications will be integrated into this initiative.

It is clear there will be certain DoD applications that may help offset the high initial cost of early advanced automotive battery production prototypes. At the same time, automotive and commercial vehicle use would bring about economies of scale and lead to low production cost and high reliability.



Coordination of defense and commercial requirements will enable capitalization on existing synergies without compromising areas of divergence.

II. Motivations

Defense Capabilities

Operational needs drive the military's pursuit of advanced automotive batteries. Chief among these needs are reliability and cost. Three key aspects of the current investment portfolio include technology developments to improve performance characteristics, manufacturing technology (MANTECH) developments to establish basic manufacturing

capabilities, and specialized Defense Production Act (Title III) activities for space batteries.

- Improved stand-by/Silent Watch power for current combat vehicles is a leading candidate for application. This application is currently being investigated on a limited basis by TARDEC for the PM Heavy Brigade Combat Team. Current combat vehicles have requirements to meet extended duration Silent Watch that cannot be met with existing batteries or auxiliary power units.
- Advanced automotive batteries are a critical component in developing military hybrid vehicles. In 2006, the Joint Requirements Oversight Council (JROC) gave direction to selectively apply energy efficiency as a key performance parameter to DoD acquisitions.
- Hybridization of military platforms has been long investigated as a means to improve energy efficiency. Actual efficiency gains depend largely on platform considerations and use profiles, but leading indicators suggest that military hybrids will be at least 10% more energy efficient than conventional vehicles.
- Certain medium-to-heavy-duty vehicle applications can exceed 50% fuel efficiency improvements, particularly when extended export power functionality is part of the overall duty cycle. These results were gathered under operational testing on pre-production commercial utility trucks.
- Projected non-propulsive electric loads can vary from about 2% on current main battle tanks to roughly 10% on future manned ground combat vehicles. System hybridization is a key enabler to meet these demands and to most effectively manage platform power. These needs are emphasized by the recent call from the Program Manager for Future Combat Systems for more advanced automotive battery development.
- On-board electrical power demand continues to grow rapidly in military tactical vehicles, and is difficult to manage with existing electrical and energy system designs. Enhanced energy storage options and hybridization electrical system can add enhanced functionality, flexibility, and power quality benefits to a redesigned vehicle. It is a key element of more capable tactical and combat vehicles.
- Proper development of sophisticated battery management systems for charge balancing, charge/discharge rate control and over/under-voltage protection limits needs to be addressed. Another key factor is an integrated design that addresses the packaging needs for thermal management over the range of expected operating environments

Energy Security and National Security

Today, petroleum fuels 96% of the total transportation needs, and also provides feedstock for the manufacturer of millions of products within the United States. To meet this need, petroleum sources are increasingly imported from overseas and from regions of the world which are unstable or outright unfriendly to national interests.

U.S. petroleum production has already peaked and does not meet domestic consumption. The nation now imports more than 60% of its petroleum, up from 40% just thirty years ago (source: US Energy Information Agency). The biggest user of this energy is the transportation sector. As much as two-thirds of this imported oil comes from the Middle East and OPEC nations, the purchase of which essentially transfers billions of dollars of wealth out of the country.

Therefore, reducing or displacing petroleum use is of paramount national security interest. One of the key ways to reduce petroleum demand is through the implementation of a variety of energy efficient platforms such as electric, hybrid electric, hybrid fuel cell, and extended electric range plug-in vehicles. Enhanced and advanced energy storage is critical to the commercial and operational success of these platforms.

Decreasing petroleum demand will alleviate short term concerns while advancements in science and technology will solve the long term energy security issues associated with a secure, clean, and affordable energy solution. Currently, electrochemical energy storage technologies are the most likely known candidates to complete this vision quickly and affordably.

The U.S. is at risk of becoming captives of imported energy storage technologies just as it has for petroleum. While this has an impact on commercial competitiveness, it also presents a risk that there will be limited access to foreign energy storage products in the future for military applications. While cutting back on petroleum demand can alleviate short term concerns and is important, only advancements in science and technology will solve the long term energy security issues associated with a secure, clear, and affordable energy solution. Electrochemical energy storage technologies are the most likely candidates known today to complete this vision.

Electrochemical technologies, storage and support systems are critical components of energy-efficient vehicle design and enhanced military capabilities. Because of this, a strong domestic manufacturing base is deemed of high importance to the nation's security and ability to manage its energy future. The ability to provide unfettered (militarily or politically) access to advanced energy storage in times of international conflict is equally important and of concern, since currently most battery manufacturing of advanced chemistries is non-domestic with a high percentage coming from China.

Domestic Competitiveness:

Achieving Corporate Average Fuel Economy (CAFE) results of 35 miles per gallon by 2020, requires the implementation of advanced powertrains. Improved battery technologies are a critical part of these solutions. While there are many domestic start-up and development companies in the energy storage realm, most current manufacturing-level activities are overseas. Therefore, the nation is at risk of losing control and leadership of this capability, which will represent an increasing percentage of the value of vehicles. It is worth noting that where the U.S. has shown development and manufacturing leadership, it has both created a base for its own industry and a potential export product. Recent examples in the clean-fuel engine and heavy-duty hybrid markets

have shown that U.S. products can be competitive when they are high-value and leading-edge.

The implementation of a domestic source of advanced automotive battery manufacturers will create a large number of U.S. jobs. It will create high-value jobs in research and product development, and high-paying jobs in the technologically advanced manufacturing plants. Rather than risk losing these jobs to foreign component and vehicle competitors, investing in this technology now will retain jobs domestically. This initiative presents an opportunity to rebuild and maintain our industrial base and transition it to the technologies of the future.

III. Desired Outcomes

- ❒ Establish a cost-competitive, flexible domestic production base of high-quality advanced automotive battery materials and components that have dual-use applications to both military ground vehicles and commercial vehicles by 2015. There will be opportunities to improve upon the 2015 time frame and there is the possibility of establishing U.S. Advanced Automotive Battery production as early as 2010 on limited low level production capabilities.
- ❒ Demonstrate supply base flexibility by producing multiple cell designs, and be adaptable to evolving combinations of electrode, electrolyte, and separator material sets in a more automated fashion.
- ❒ Validate the capabilities of the supply base by evaluating advanced energy storage systems under representative military and commercial operational cycles.
- ❒ Determine and establish common military and commercial performance-based needs for domestic energy storage components and systems, and aggregate potential common demand to demonstrate and signal manufacturing volume goals.
- ❒ The output of the production base must meet military and automotive sector requirements for safety.

IV. Key Stakeholders and Roles

Battery material suppliers

Any effort to establish a domestic supply base for advanced batteries needs to give consideration to the suppliers of materials. Many cell manufacturers currently rely on foreign sourcing for raw materials. The base for materials manufacturing needs to developed in-parallel with, or possibility before, the cell manufacturing. Slight changes in the materials manufacturing process can have a significant effect on life of batteries. This change likely will not be detected until years later and cannot be detected by in-coming inspection of the material specification.

Cell Manufacturers

There are many existing and emerging small domestic companies. However, current U.S. suppliers require a fully automated manufacturing process to reduce the high cost of labor and allow them to compete in the world market. Complete automation necessitates an

investment in capital equipment such as mixers, coaters, drying ovens, calendering mills, electrode slitters, cell winders, electrolyte filling and formation equipment. Unfortunately, the cost to leverage their manufacturing capabilities within the U.S. is prohibitive without substantial government investment and clear market signals.

Currently, cell manufacturers rely heavily on foreign sourcing for raw materials, intermediate products, and manufacturing process equipment.

Pack Integrators

The current base of pack integrators is maturing at a slow rate, and this is an opportune time to leverage their research and development to enable a U.S. source of manufacture.

Several of the Tier 1 automotive suppliers have been developing expertise in the area of advanced automotive battery pack integration. This expertise requires knowledge of thermal management and battery management at the pack level. This will depend upon knowledge and experience in the disciplines of systems engineering / requirements analysis, structural analysis, thermal analysis, control theory and system modeling, simulation, design of electronics for automotive environment, and high voltage safety compliance – which is over and above the expertise of battery cell developers.

High volume production will dictate cost reductions for the total battery system, which will drive additional investments in the battery system's thermal management system, wiring harness and high power connection systems, current sensors and high voltage contactors, structural housing elements and battery management controller with battery cell equalization.

To enable viable Plug-in Hybrid Electric Vehicles (PHEVs) and Electric Vehicles (EVs), additional functionality of the overall energy storage system must be included. Pack integrators will also be required to upgrade the battery thermal management system, include on-board charger circuits and possibly interfaces to higher-rate off-board chargers. Pack integrators will also be required to integrate the chargers into the controls of the battery management system, and possibly seek UL certification, all requiring additional investments.

Automotive

The United States has been a leader in advanced battery development for many years and many believe that the time has arrived to take the steps required to enable the large-scale manufacture of advanced automotive batteries.

Developing requirements and schedules for large scale deployment is a prerequisite for successful creation of a domestic capability to manufacture advanced automotive batteries.

There are, and will continue to be, heavy cost pressures and a need for economies of scale to enable advanced automotive battery manufacturing within the US.

Heavy Vehicle OEMs

Heavy vehicle OEMs provide manufacturing and platforms that are more closely aligned to military tactical vehicle needs than light duty passenger. Incorporating these players into the energy storage demand and performance equation will enhance the value to the military of the components and the manufacturing capability developed.

Bus makers and truck makers will be valuable because they are often the first movers and users of advanced technology, as shown by the 15% penetration rate of hybrids into the transit market and the early demonstration of fuel cell systems in transit applications.

Defense Ground Vehicle OEMs

Defense Ground Vehicle OEMs will be a major user of these technologies. Gathering their requirements ensuring integration of the technologies will enable a domestic source of advanced automotive batteries that meets their needs.

Dual use products from tactical vehicles will also enable a larger market demand to maintain a manufacturing base that will always exist to meet defense needs.

Recycling Facilities

Participants from this arena will define and develop technologies that will be used in advanced automotive battery recycling facilities to meet or exceed economic and environmental requirements. Incorporating the end of life-cycle requirements from the beginning of the project will ensure that the advanced battery technology is a complete success.

Federal Government

There are several unique DoD performance requirements. Army, Navy, and Air Force (including ManTech) will provide opportunities for leveraging and exploiting potential government funding opportunities for this initiative to ensure that those requirements are met or exceeded.

- ❒ The Defense Production Act (DPA) is a United States law enacted on September 8, 1950, in response to the start of the Korean War. It was part of a broad civil defense and war mobilization effort in the context of the Cold War. The Act has been periodically reauthorized and amended, and remains in force as of 2008. Beginning in the 1980s, DoD began using the contracting and spending provisions of the DPA to provide seed money to develop new technologies. Using the DPA, DoD has enabled the development of a number of new technologies and materials, including silicon carbide ceramics, indium phosphide and gallium arsenide semiconductors, microwave power tubes, radiation-hardened microelectronics, superconducting wire, and metal composites.
- ❒ The Army supports several programs fielding, demonstrating, and testing advanced capabilities in military and commercial vehicles. The technologies supported include hybridization, silent watch and mobile grid, and can provide a prime resource for validation testing and assessment of new, domestic energy storage systems.

- The Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EERE) conducts activities in partnership with the private sector, state, and local government, DOE national laboratories, and universities. Additionally, the DOE can provide valuable insights on the applications outside of the automotive sector to include; renewable energy, telecommunications back-up and utility peak power sources
- Several of the national laboratories have expertise in testing and evaluating advanced automotive batteries.
- The Department of Commerce executes a critical economic development role and this perspective will be very helpful in executing the development of a domestic base for advanced batteries.

V. Proposed Approach

The first step to defining the advanced automotive battery initiative is to hold a Battery Planning Summit where military and commercial vehicle users will begin to develop a multi-year strategic plan and reach a consensus on the near-term approach required for launching and executing the initiative. This summit was held in Troy, MI on November 18th and 19th, 2008. During the Summit, key stakeholders were identified and their potential future roles were discussed.

At the conclusion of the Battery Planning Summit, a Battery Roadmapping Forum will be planned, including invitations to all identified stakeholders. It is presently anticipated that the Battery Roadmapping Forum will comprise the following:

- Stakeholders from federal government agencies and the advanced battery and vehicle industries will define the requirements and map a strategic path forward based on the outcome of the forum.
- The primary goal of the forum is to reach a broad consensus on the general scope and direction of the efforts required to mature a domestic base for the production of advanced automotive batteries within the U.S.
- Additionally, agreement will be sought on the development of a plan to move forward with the initiative and to begin the process of securing the resources needed to execute the plan.
- A component of this strategic plan is the plan for the creation of battery manufacturing development /pilot plants.

VI. Policy & Legislation

The Advanced Automotive Battery Initiative is a critical element of developing an advanced energy storage manufacturing capability in the United States and securing American sources of and leadership in this enabling technology. However, it is also just one important component of a comprehensive approach that can speed American capability. To ensure faster action and success requires a suite of policy tools to support energy efficiency, American technology leadership and petroleum reduction, including

joint investments, manufacturing tax credits, purchase and use incentives and greater funding of research and development, including in materials science.

A comprehensive, generational national energy policy that supports and drives energy efficiency will be an important driver supporting the need for and investments in advanced technologies and energy storage capabilities. Additionally, the following aligned policy efforts will provide greater speed in encouraging investment and increasing production:

- ❒ Spur domestic production, via incentives, producer credits or other tools to reward manufacturing in the United States.
- ❒ Spur domestic demand, via government purchase actions that include GSA and military commitments to buy increasing numbers of advanced high-efficiency vehicles; credits for purchase of US-manufactured systems; tax credits for consumer purchase of advanced vehicles; rebates/grants for high efficiency commercial vehicle purchase; and aggregating demand for common batteries across market segments.
- ❒ Send long term price and market signals of the value of efficient technologies, through fuel price or other mechanisms.
- ❒ Expand and consistently support investments in research, development, testing and evaluation of advanced energy storage, from materials science, manufacturing processes and production tool development through battery pack and vehicle integration and deployment.
- ❒ Use a coordinated effort across the full continuum of federal agencies to direct this effort, from early stage research through vehicle deployment and assessment.
- ❒ Encourage greater component commonality and industry standardization to drive volumes and help reduce price.

VII. Potential Plan Elements

The following elements are proposed for the advanced automotive battery initiative plan. As the elements are presented below there is an opportunity to improve upon the scheduled program years; however, the risk should be considered high.

	Year 1	Year 2	Year 3	Year 4	Year 5	
Dual Use Energy Storage System Development						$75M
Pilot Plant Construction						$500M
Plant Operation						$100M
Fleet Operation						$75M
Manufacturing Equipment Development						$50M
Raw Material Production Base						$50M
Full Scale Plant Development						$100M

Dual Use Energy Storage System Development

Define battery cell and module manufacturing requirements to support technical scope. Critical characteristics include initial plant size and production rate, production line equipment needs, real-time quality control systems and processes, secondary production processes, scale up planning, and building permits.

Define dual-use requirements and identify key characteristics which influence battery cell and module manufacturing. Maximizing commonality between military and commercial batteries will serve to reduce overall production costs by limiting the need for manufacturing flexibility to address unique requirements.

Develop testing and resource requirements and identify any resource gaps

- ❒ Manufacturers can employ existing cell and module testing equipment (battery cyclers, thermal chambers, data acquisition, etc.) for the evaluation of pilot-scale contract deliverables
- ❒ In cases where manufacturers do not have access to adequate testing resources, identification of outside sources will be required
- ❒ Sources of independent contract deliverable testing such as third-party contractors and national labs will be identified where required
- ❒ Should inadequate domestic test resources exist, a gap assessment will be conducted in order to define additional requirements and timing

Develop technology needs assessment and gap analysis. Where mission critical needs are identified, but available technology solutions prove inadequate, a technology gap assessment will be conducted in order to define R&D needs.

Pilot Plant Construction

In addition to immediately launching into a series of developments to ensure dual-usability of advanced automotive batteries, it is critical to begin construction of pilot plants. These plants will be based on current state of the art practices and equipment. Getting such plants built early in the initiative is important to avoid having to displace such capabilities which are on the verge of being established elsewhere in the world. The approach should provide for multiple seeding and co-investments to speed the capability, rather than build plants from scratch. These plants will serve as the venues for initial implementation of advances sought in raw material production and manufacturing equipment development. The output of these plants will provide the batteries for the fleet use of advanced powertrain vehicles in subsequent years of the initiative.

Plant Operation and Cell Production

It is advisable to have support within the Initiative for the fixed operational costs of the pilot plants. The variable production costs would be paid by DoD and commercial battery orders.

Fleet Operation

As the battery production ramps up and is qualified, funds should be made available to spur the use of these advanced batteries by the DoD and commercial users. These batteries will still be considered to be high risk technologies by many fleets acquirers and users. The funds will be applied to mitigate these risks to ongoing or new vehicle production programs.

Manufacturing Equipment Development

Initial implementation of the pilot plants would source the manufacturing equipment from existing suppliers. To have a sustainable domestic battery industry it will be critical to move toward a domestic base for manufacturing equipment. Some of the plant operations are listed below, particular areas for increased development will be identified by the stakeholder community.

- ❒ Coaters
- ❒ Slitters
- ❒ Calendering mills
- ❒ Winders
- ❒ Formation
- ❒ Powder processing
- ❒ Raw materials production
- ❒ Mixing
- ❒ Busing & closing (cell level)
- ❒ Electrolyte Filling
- ❒ Testing equipment

Raw Material Production Base

To establish a truly domestic battery production base, the Initiative should include efforts to establish U.S. sources as far down the value chain as possible. This includes the active chemicals and intermediate products such as separators and current collectors. Activities under this plan element could include research into chemical synthesis techniques, manufacturing scale up and optimizing. Additionally, an important aspect of this element should be investigation into the recycling and reuse of active materials due to the lack of certain required natural resources in the United States.

Full Scale Production Plant

In the final years of the Initiative, additional funding should be made available to incentive the construction of full scale battery production facilities. The private sector should bear the majority of the costs at this point but additional government funding should be made available to maximize domestic content of any new plant construction or expansion in this time period.

VIII. Appendices

Stakeholders

The listing below identifies the organizations and individuals contacted during the preparation of this paper and/or participated in the Battery Summit in November 2008.

University of Michigan	Booze Allen	Quandary Solutions LLC
ARL	Boston Power	Qynergy
Army CERDEC	Chrysler	Ricardo
Air Force	Compact Power	RSR Technologies
DOE	CTC	SAFT
FCS	Dow Chemical	JCS
FFID	EaglePicher	SAIC
MEDC	EnerSys	SCRA
National Research Council	Ford	USABC - USCAR
NSWC - CRANE	General Electric	Quallion
Oak Ridge National Lab	GM	Yardney
OSD	GS Yuasa Lithium Power	CALSTART
PM Stryker BCT	3M	Next Energy
Senate Arms Service Committee	Delphi	Cobasys
TARDEC	IMTI	Electrovaya
Sandia	Inanovation	PowerGenix
TRADOC	International Battery	EnerDel
A123 Systems	AIMARA	Continental
ABDG	Military Battery Systems	Exide
AeroVironment	NEI Corporation	Kokam
BAE	ECD Ovonics	Electric Fuel

Defense Production Act Title III

The mission of the Defense Production Act (DPA) Title III Program (Title III) is to "create assured, affordable, and commercially viable production capabilities and capacities for items essential for national defense." The Advanced Automotive Battery program fits well with the overall mission of the Title III Program and it should be considered as the funding vehicle.

The direct and indirect benefits to defense programs resulting from Title III initiatives are substantial. By stimulating private investment in key production resources, Title III would help to:

- Increase the supply, improve the quality, and reduce the cost of advanced materials and technologies needed for national defense;
- Reduce U.S. dependency on foreign sources of supply for critical materials and technologies; and
- Strengthen the economic and technological competitiveness of the U.S. defense industrial base.

Title III activities serve to lower defense acquisition and life-cycle costs and to increase defense system readiness and performance through the use of higher quality, lower cost, technologically superior materials and technologies.

It should be noted that Title III has already funded a project for the development of a domestic materials capability for cathode and anode materials for aerospace lithium ion batteries. Thus, there is a model in existence for how to set up and run such a program. This current program is not large enough to support the commercial automobile requirements.